

Mission Concept for a Europa Lander

March 4, 2018

Jennifer Dooley & the Lander Mission Concept Team
Jet Propulsion Laboratory, California Institute of Technology



National Aeronautics and Space Administration



EUROPA LANDER STUDY 2016 REPORT

EUROPA LANDER MISSION

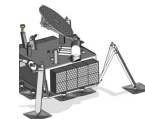
JPL D-97667

TASK ORDER NNN16D011T

EUROPA LANDER MISSION PRE-PHASE A



EUROPA LANDER MISSION CONCEPT TEAM



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Gannon, M.	Iskow, J.	Porter, J.
		Roth, D.
		Schwartz, P.
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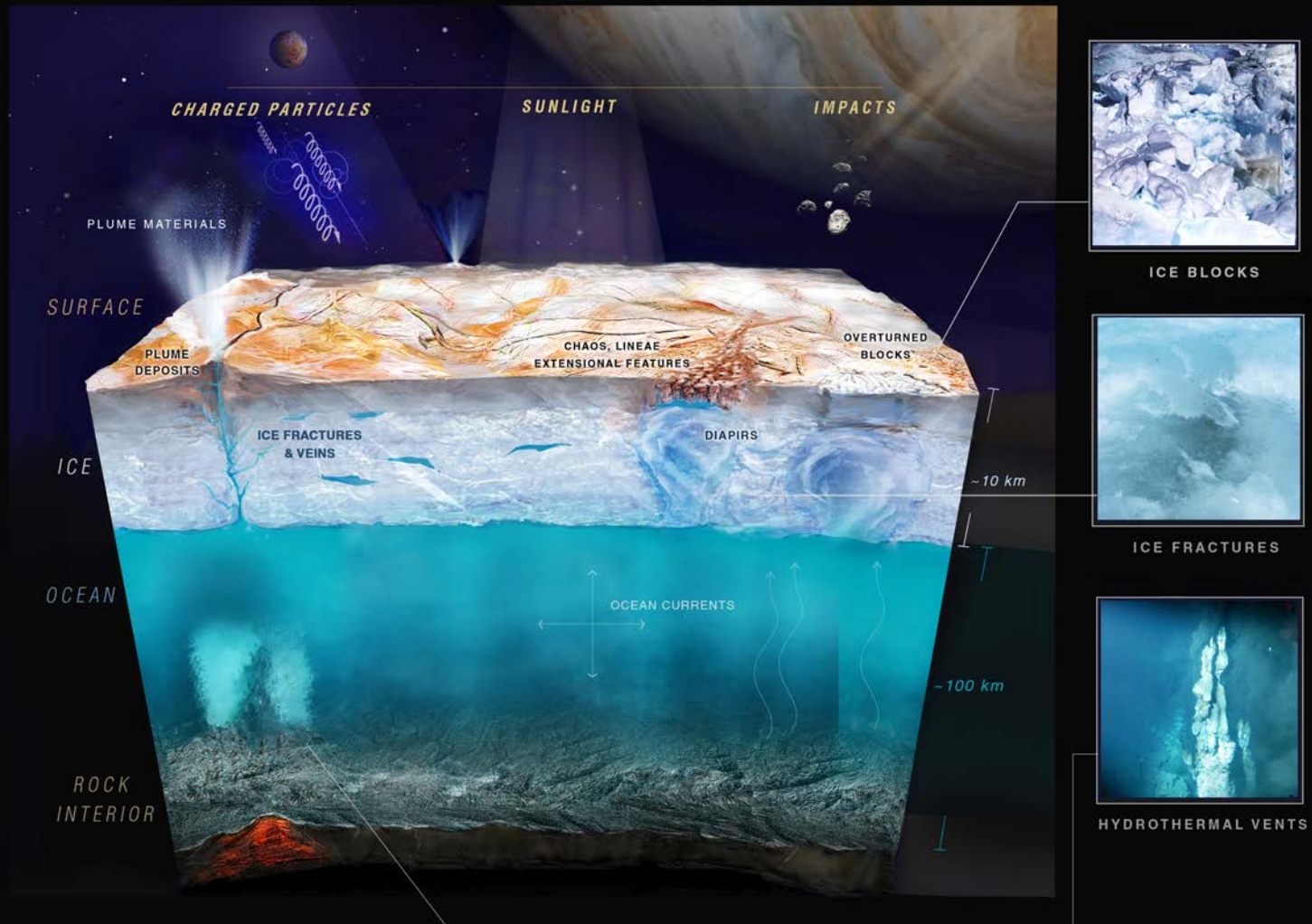
Goddard Space Flight Center

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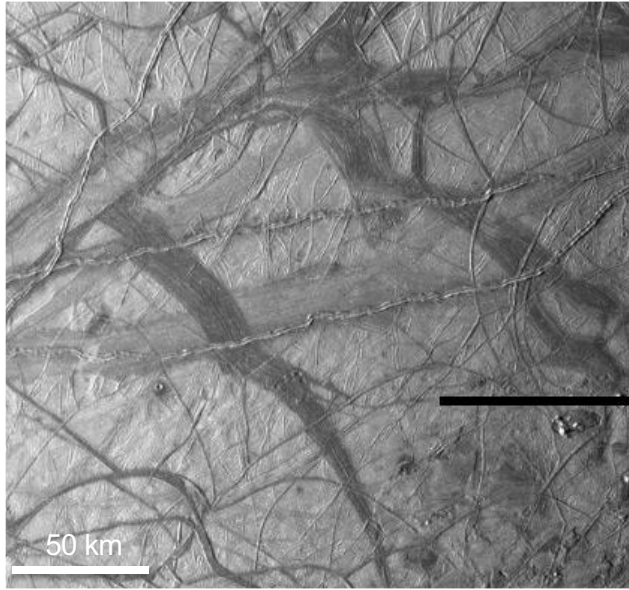
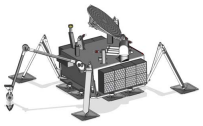
Marshall Space Flight Center

Adam, J. R.	Betts, E.	Norwood, J.
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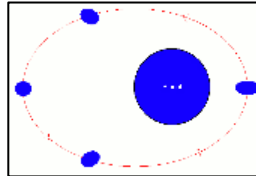
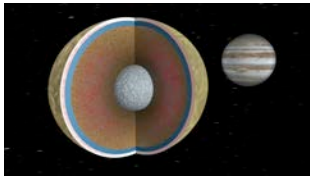
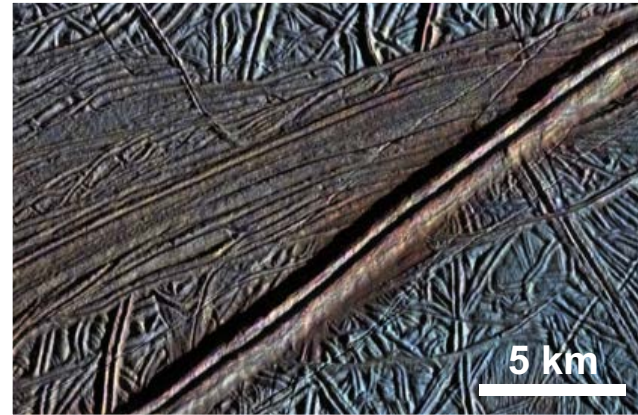
EUROPA



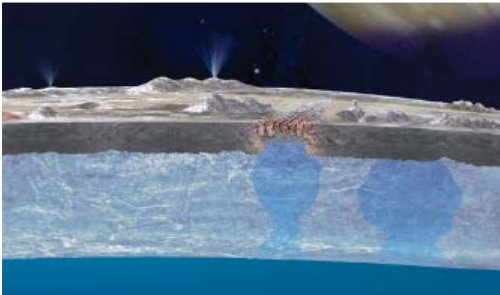
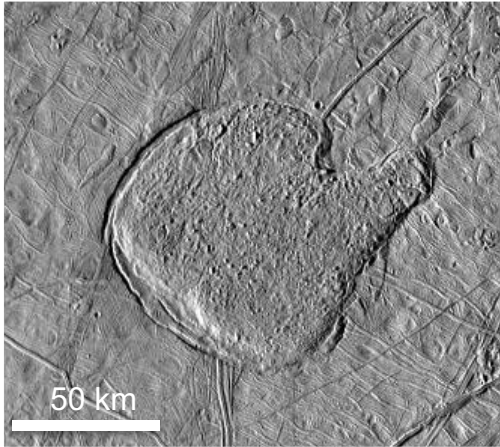
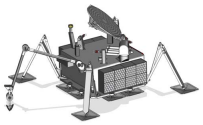
Global tectonic activity



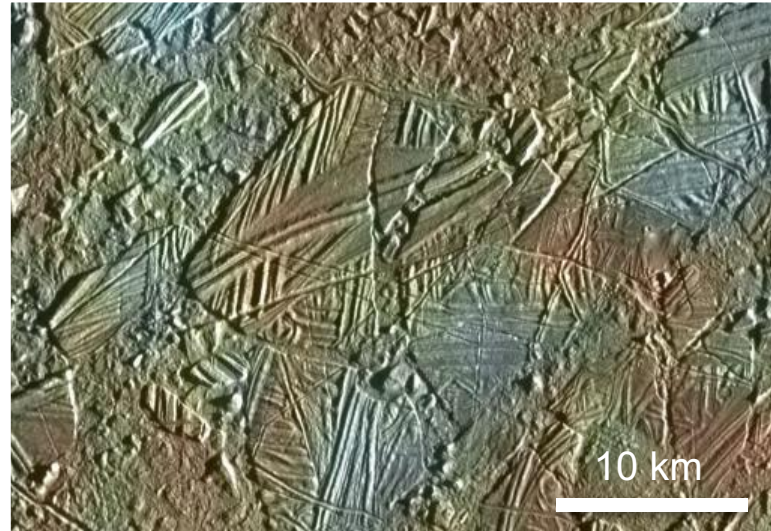
- Surface is criss-crossed by bands and ridges in all orientations, and at all scales
- Driven by tidal squeezing causes cracking on the surface
- May have plate tectonics system



Extensive cryovolcanism

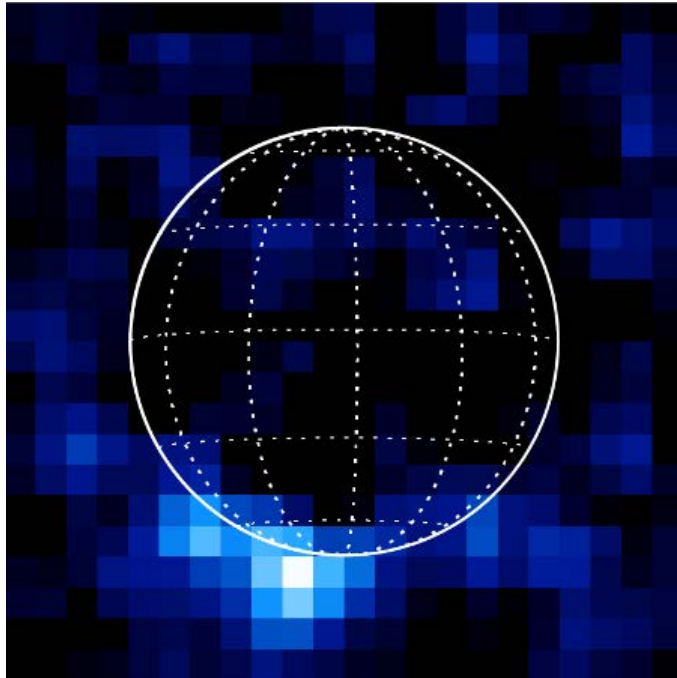
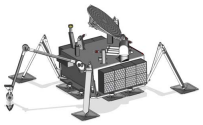


- Evidence of solid-state and liquid water volcanism
- Chaotic terrain consists of plates, matrix
- Energy from tidal squeezing likely causes convection and melting in the ice

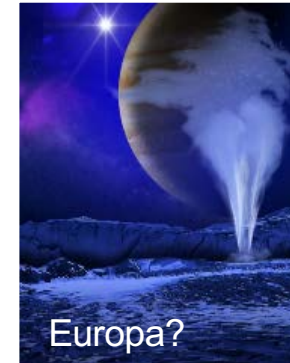




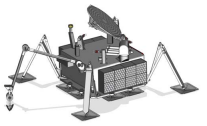
Possible plumes of water



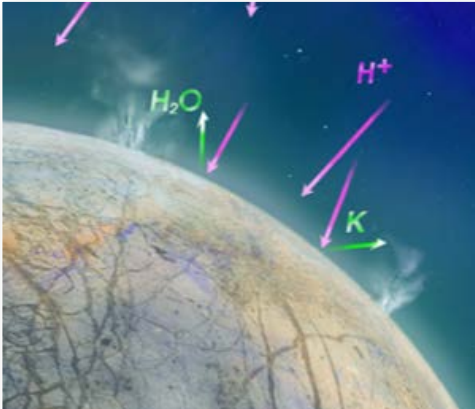
- Recent Hubble observations of hydrogen and oxygen ions concentrated at high southern latitude
- Interpreted as plumes of water vapor ~200 km high



Surface chemistry of salts and acid

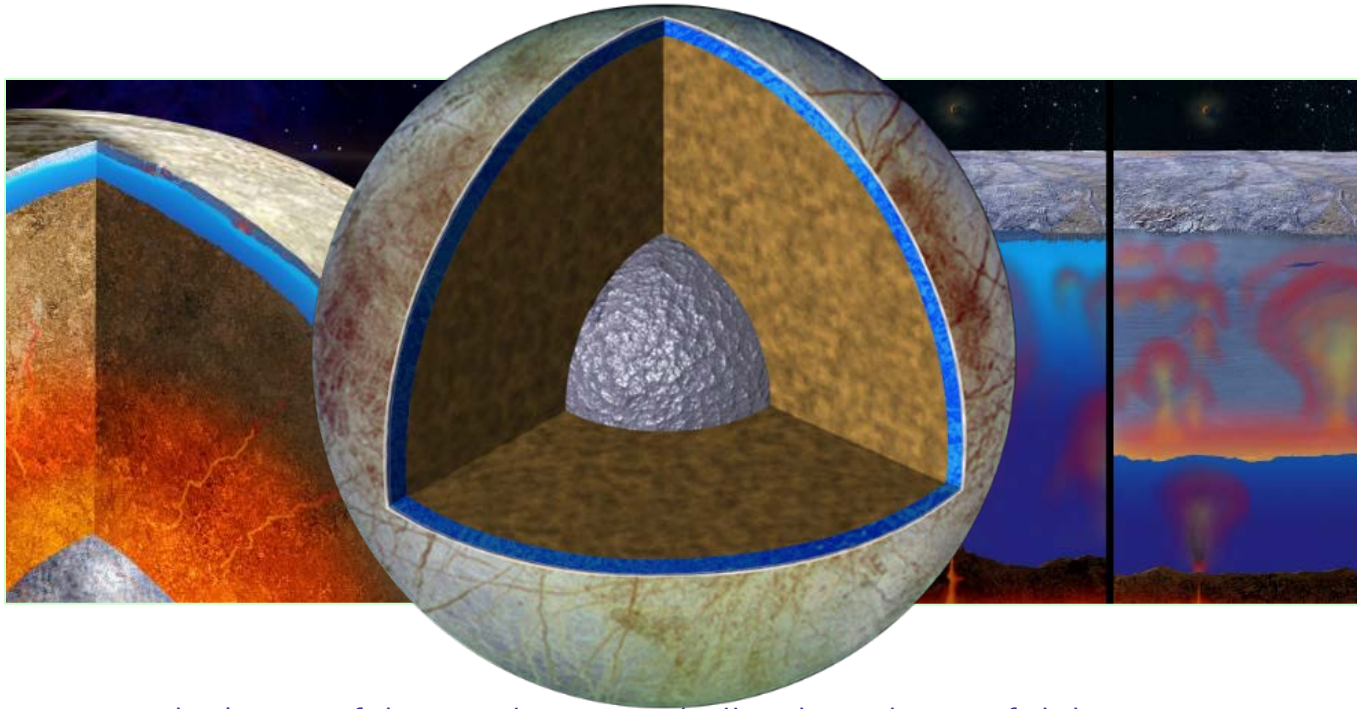
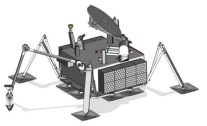


- Surface is bombarded by charged particles from Jupiter's magnetosphere
- Interaction of these particles with the surface leads to intriguing chemistry





Magnetometer + gravity data indicate a ~100 km thick subsurface liquid water ocean at Europa



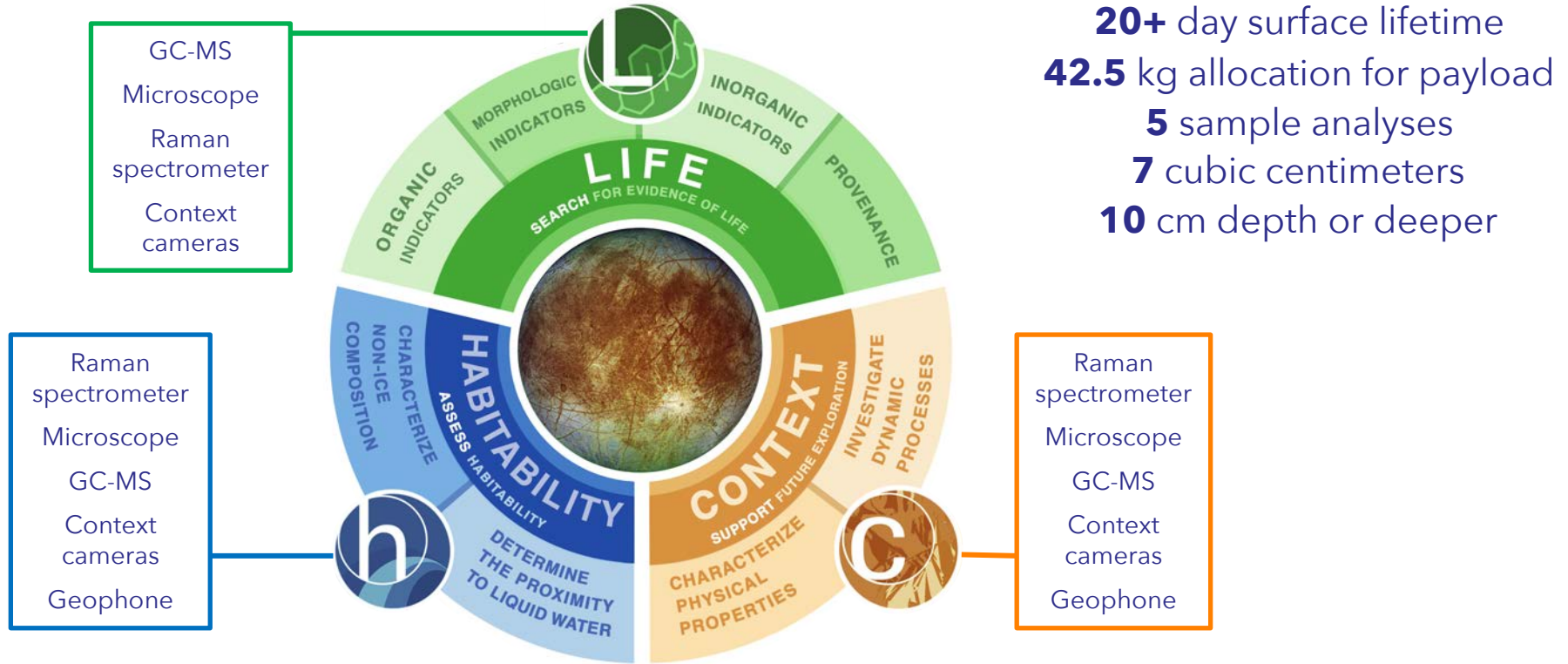
Thickness of the overlying ice shell is the subject of debate
- estimates range from a few km to ~30 km



Science Definition Team Recommendations



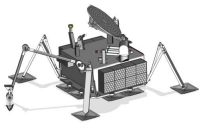
A connected set of goals and objectives addressed with a focused model payload



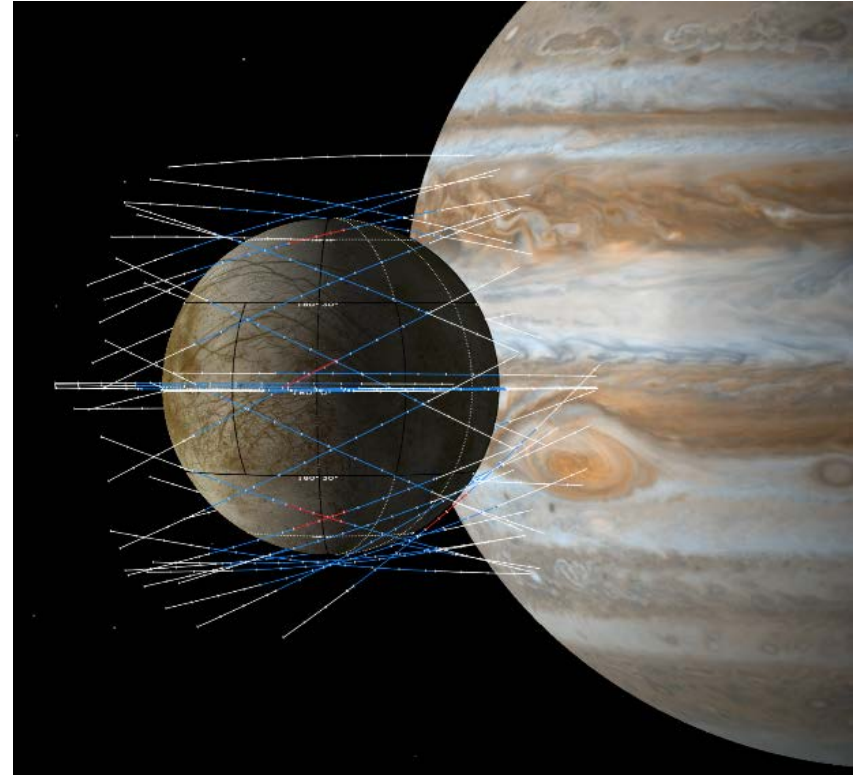
20+ day surface lifetime
42.5 kg allocation for payload
5 sample analyses
7 cubic centimeters
10 cm depth or deeper



Clipper Mission Concept

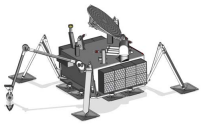


- Utilize multiple satellite gravity assists to enable “global-regional coverage” of Europa while in orbit around Jupiter
- Current mission design consists of 45 low-altitude flybys of Europa in prime mission from Jupiter orbit over 3.5 yr
- Minimizes time in high-radiation environment
- Simple repetitive operations



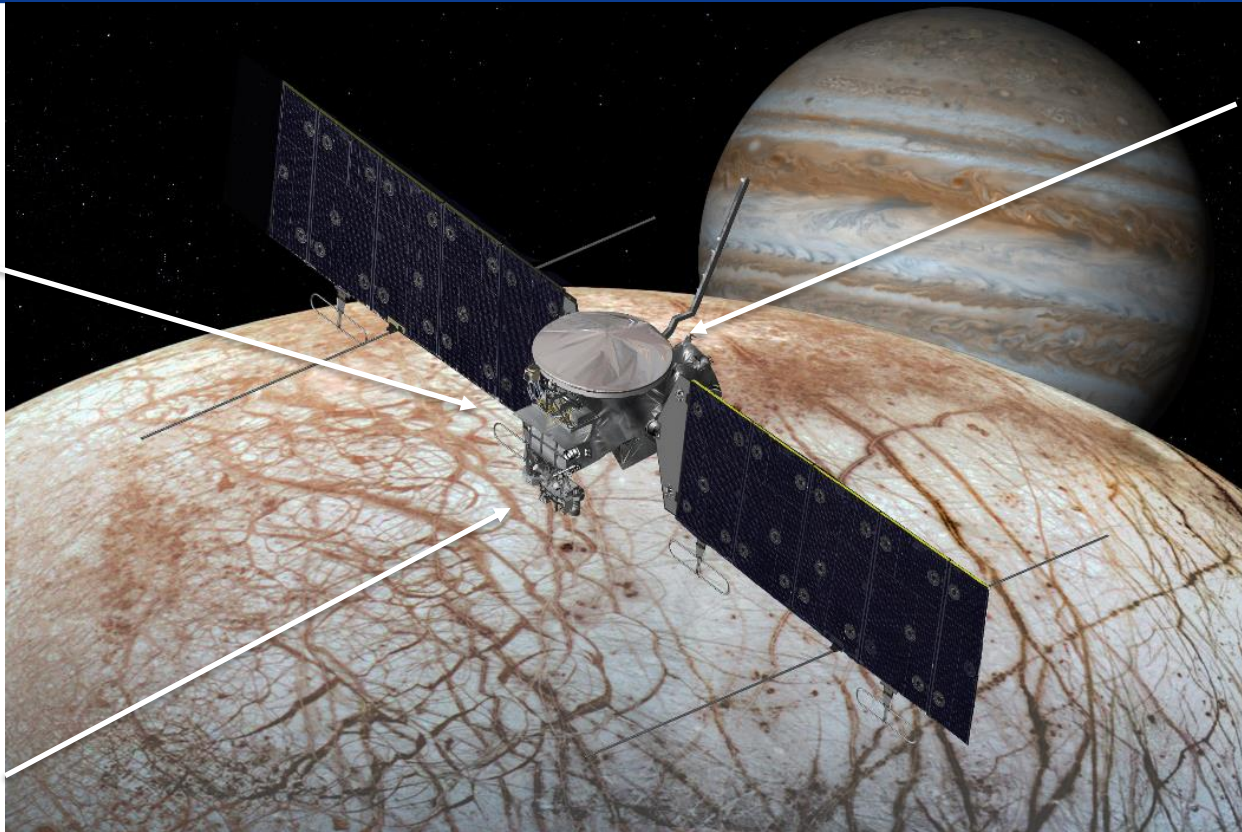


Europa Clipper



Avionics
Vault

Nadir Pointed
Instruments

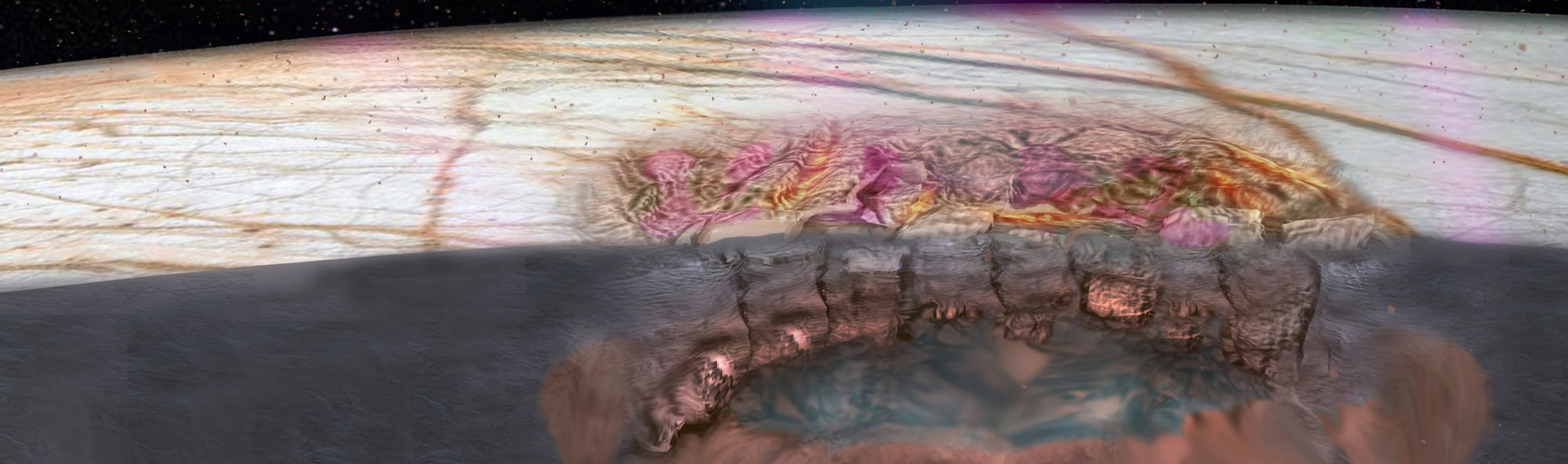


3.0 m High Gain
Antenna

~6m High
~25m Wide

Solar Array
Panels
2.2m x 4.1m
each
~87 m² area

Gravity
Magnetometry + Plasma
Imaging
Infrared
Thermal
Radar
Ultraviolet
Gas + Dust Mass Spectroscopy



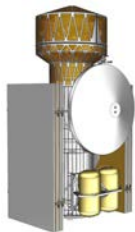


Europa Lander Mission Concept



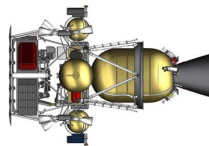
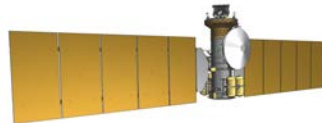
Launch

- SLS Block 1B
- Oct. 2025



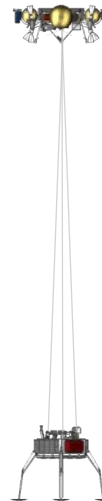
Cruise/Jovian Tour

- Jupiter orbit insertion Apr 2030
- Earliest landing on Europa:
Dec 2031



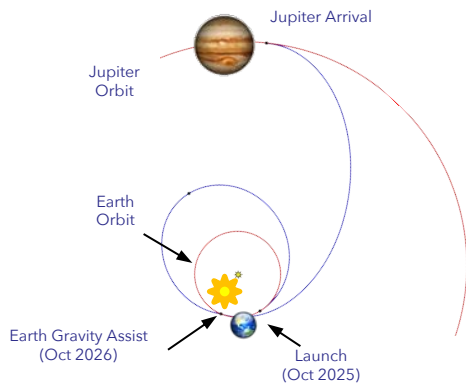
Deorbit, Decent, Landing

- Guided deorbit burn
- Sky Crane landing system
- 100-m accuracy
- 1.5 Mrad radiation exposure



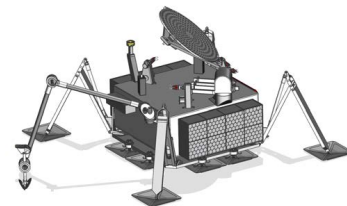
Carrier Relay Orbit

- 24 hour period
- >10 hours continuous coverage per orbit
- 3.0 Mrad radiation exposure



Surface Mission

- 20+ days
- 5 samples
- Relay comm through Carrier or Clipper (contingency)
- 5 Gbit data return
- 45 kWh battery (useable)
- 2.0 Mrad radiation exposure





Four Significant Driving Challenges



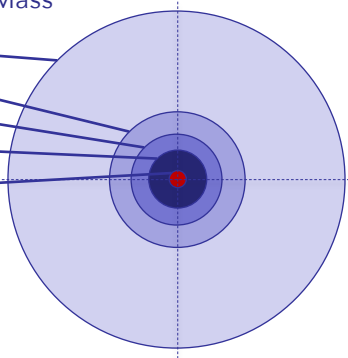
What makes the Europa Lander more challenging than Mars or Lunar landers

1 - Launch Mass



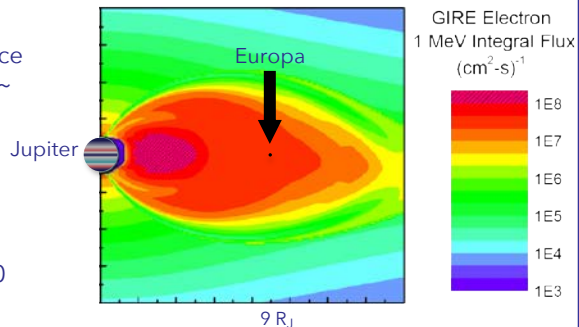
SLS BLOCK-1B LAUNCH CAPABILITY:
19,800 kg Δ VEGA
(4.6 Year Transit)

CV: 16400 KG
De-Orbit vehicle
Power Descent Vehicle
Lander
Payload 42.5 kg



3 - Jovian Radiation Environment

- Drives short surface mission duration ~ 30 day Relay Orbiter
- Vaults provide a 150 kilo-rad environment with an RDF of 2.0



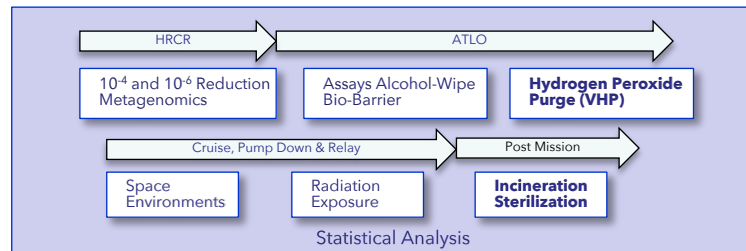
2 - Surface Topography & Properties

- Clipper Reconnaissance
- Soft Landing
- Pin Point Landing with TRN
- Hazard Detection & Avoidance
- Adaptive Stabilizers AKA Cricket
- Site Simulation - Phase A/B
- Site Selection - Phase C/D/E
- Site Certification - Phase E



4 - Planetary Protection

Europa Lander will have a less than 10^{-4} probability of introducing a single "Viable Organism" to any Europa habitable zones - Drives ATLO

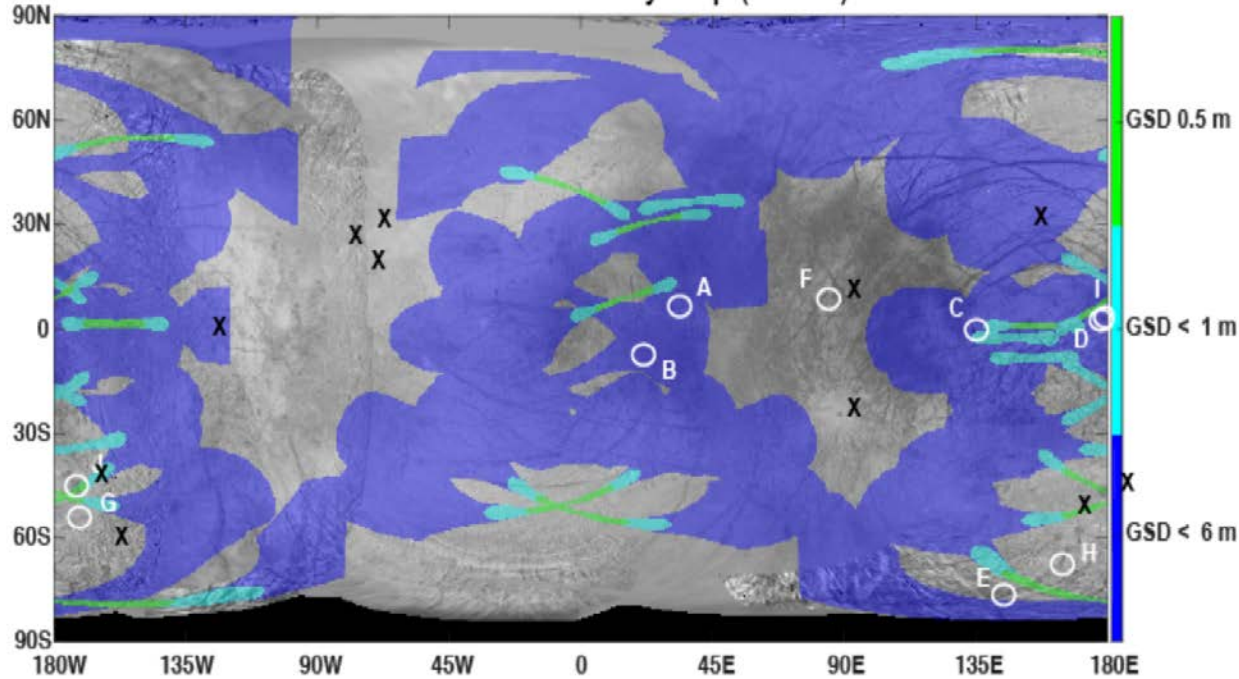




Representative Europa Clipper Narrow Angle Camera (NAC) Stereo Accessibility



NAC Stereo Accessibility Map (15F10)



EMFM's Europa Imaging System (EIS) plans to acquire visual imaging of ≥ 40 surface "sites" (site = surface area $\geq 2 \text{ km} \times 4 \text{ km}$, with $2 \text{ km} \times 10 \text{ km}$ swath coverage planned) at a pixel scale of ≤ 1 up to $\sim 0.5 \text{ m/pixel}$ and 11 m/pixel stereo over a $44 \times \sim 100 \text{ km}$ area.

Supports Digital Terrain Models with a post spacing of $\sim 3 \text{ m}$ and vertical precision of $\leq 0.3 \text{ m}$.

X: chaos regions
O: scientifically interesting sites identified in the SDT report



Europa Site Accessibility and Radiation Considerations



Three diverse sites (Yellow dots) used for concept development

ice surface

ice surface

would be radiation processed to a 60 Grad dose (100 eV/16-amu) down to 10 cm.

Latitudes in excess of $\pm 60^\circ$ are currently considered inaccessible due to TRN image sun incident angle

Blue regions are higher surface radiation zones and will require at least 10-cm sampling depth per SDT

Circular Longitudinal regions indicate no Clipper reconnaissance capability and are not considered accessible

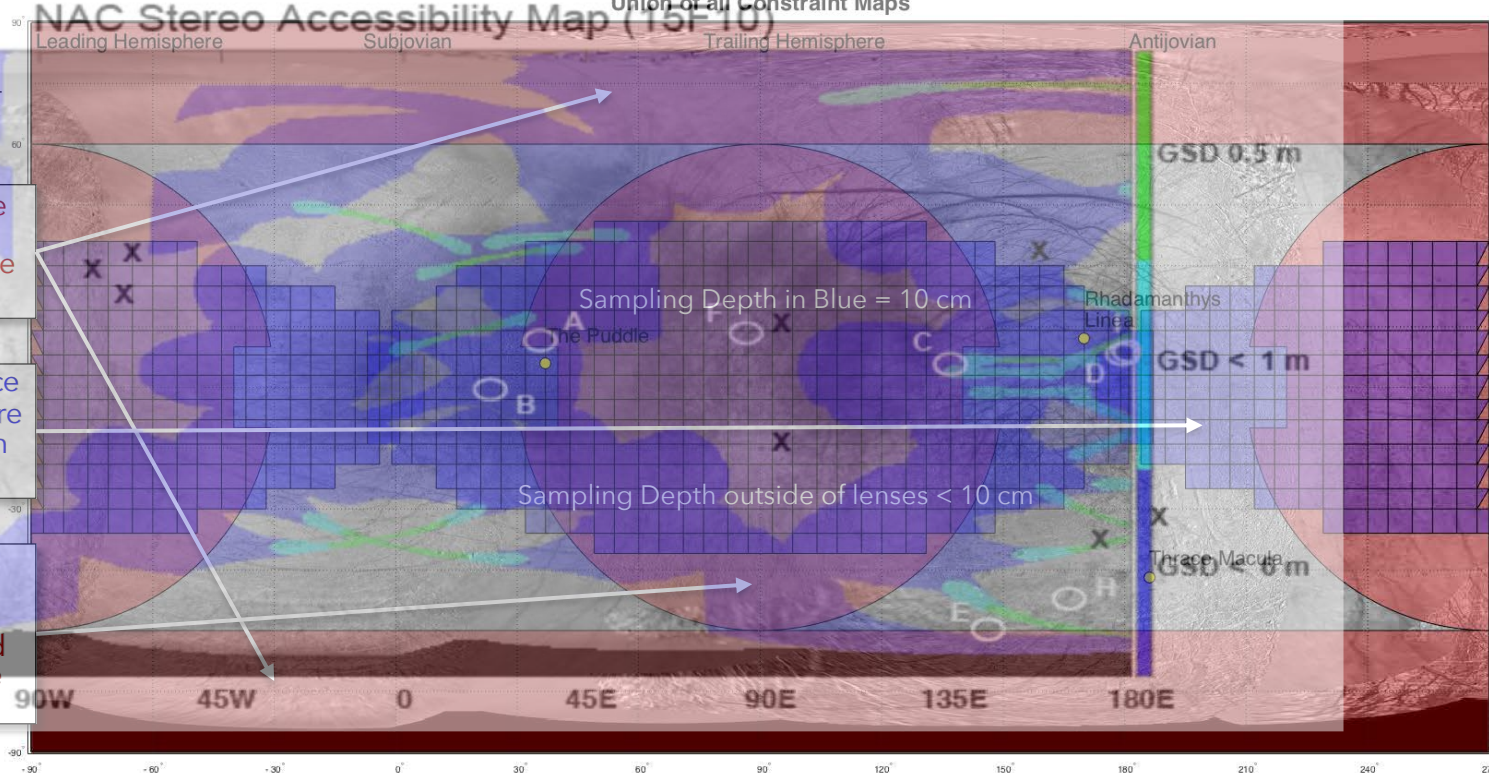
NAC Stereo Accessibility Map (15F10)

Leading Hemisphere

Subjovian

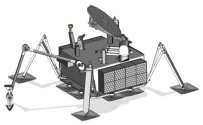
Trailing Hemisphere

Antijovian





Europa Site Accessibility and Radiation Considerations



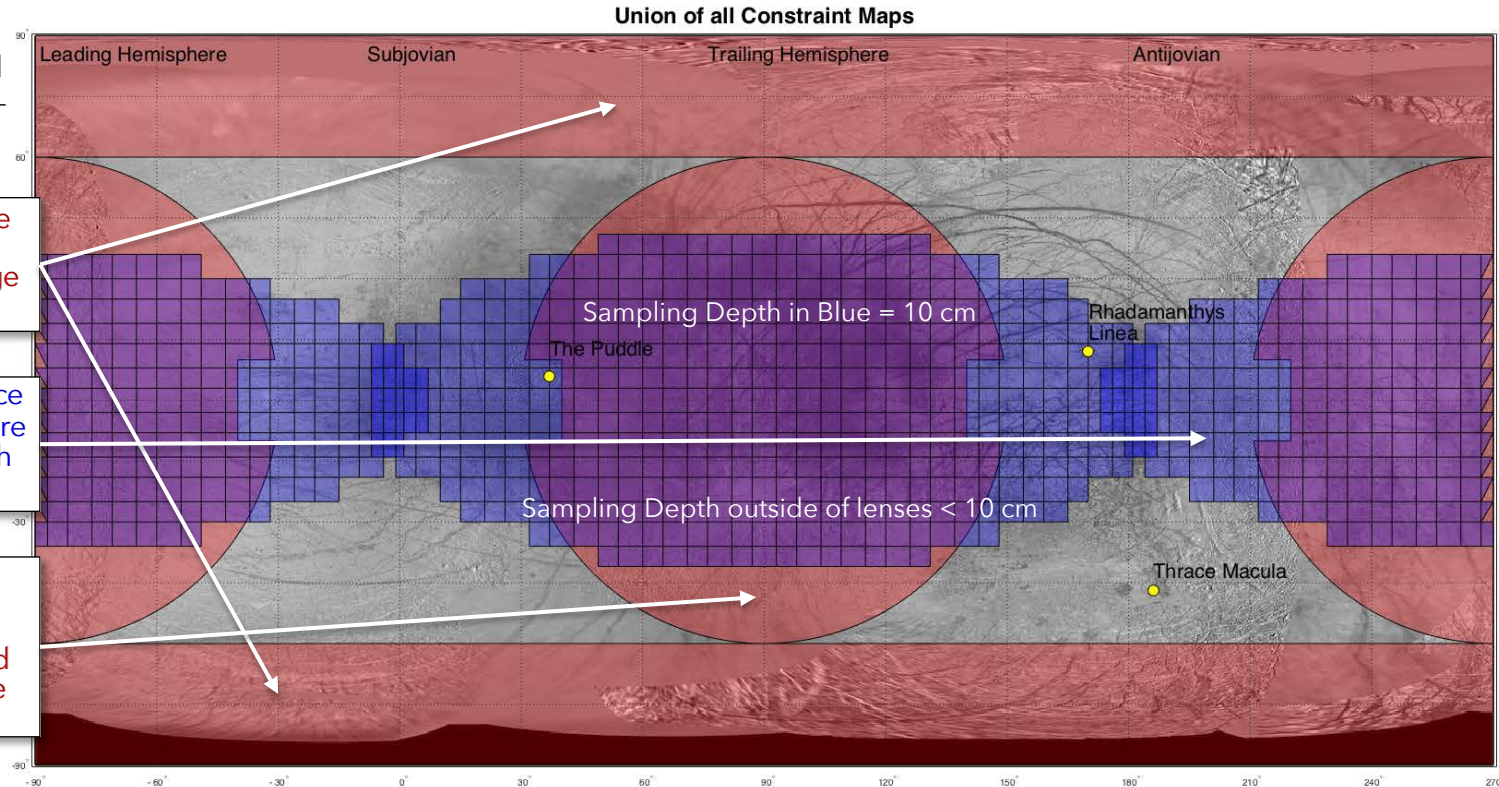
Three diverse sites (Yellow dots) used for concept development

For a 10^7 yr average surface age, a pure water ice surface would be radiation processed to a 60 Grad dose (100 eV/16-amu) down to 10 cm.

Latitudes in excess of $\pm 60^\circ$ are currently considered inaccessible due to TRN image sun incident angle

Blue regions are higher surface radiation zones and will require at least 10-cm sampling depth per SDT

Circular Longitudinal regions indicate no Clipper reconnaissance capability and are not considered accessible

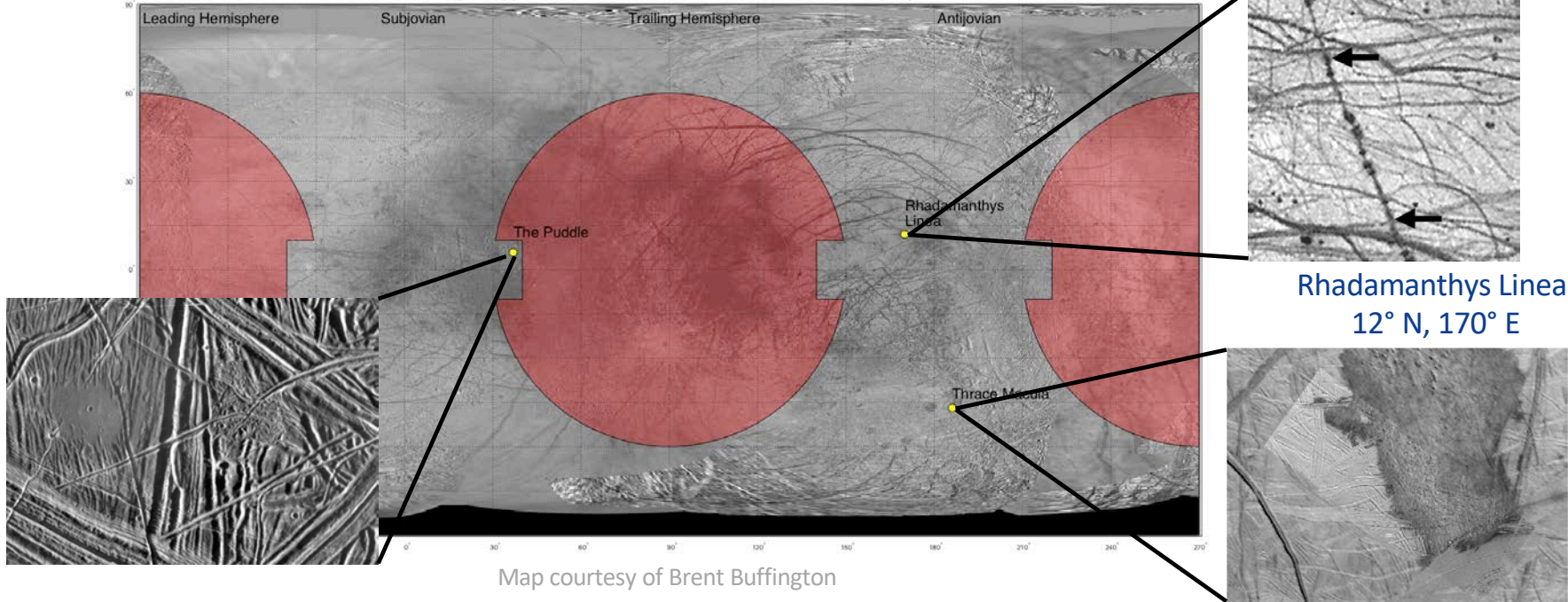




Reference Landing Sites



Europa Clipper Site Certification Reconnaissance Exclusion Map

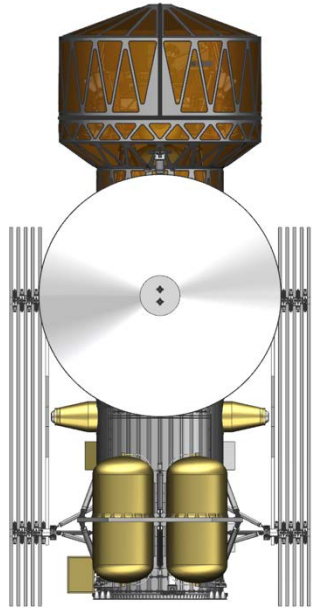
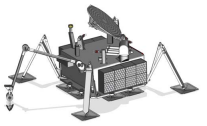


- Sites chosen consistent with Clipper Reconnaissance accessibility and based on science interest and latitude diversity

Thrace Macula
47° S, 186° E

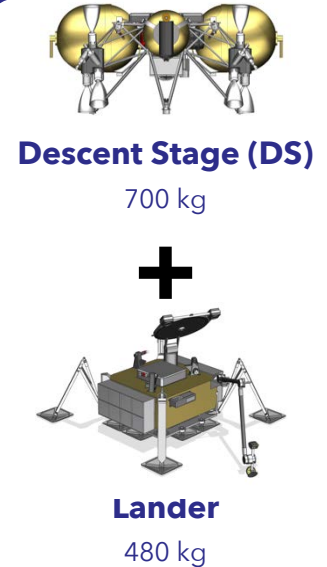
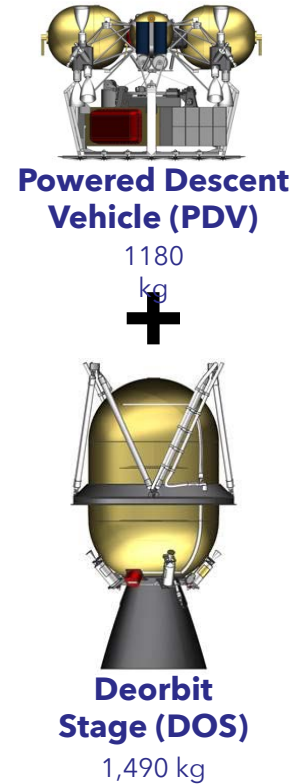


Baseline Flight System



Cruise Vehicle (CV)

Launch Mass: 16,380 kg





Europa Lander Concept



MISSION DESIGN

ΔVEGA interplanetary trajectory
($C3=30\text{km}^2/\text{sec}^2$)

Landing Site Accessibility:

- Latitude $< \pm 60^\circ$
- Longitude: wide (3-body) or $< \pm 15^\circ$ from 0/180 (elliptical)

CRS ΔV Pre-separation: 2141 m/s
CRS ΔV Post-separation: 520 m/s

Match local solar time at landing
w/in 1hr of Reconnaissance LST

Provide communication window for
15min after touchdown

DDL

DOV Periapsis velocity: $< 1950\text{ m/s}$
Coast duration: 2hrs

DDL Abort & Retry: Potentially
DDL Alternate Site: Potentially

SURFACE

Total Data Return: 5 Gbit
Responsiveness: High [20 Ground
in the loop command cycles]
Comm Faults: timely
detection/recovery

FLIGHT SYSTEM

Total Flyaway Launch Mass: 16380kg
Flight System MPV Dry Mass: 5750kg

Biprop w/Staged Prop. Tanks for DSM
CRS Solar Array Size: 2 5-panel 58.75 m^2
(117.5 m^2 total)

Deorbit Stage: STAR-37 with 20% stretch

Lander Mass: 480 kg
Stored Surface Energy: 45 kWhr
Thermal Sterilization System for PP

Dual string CRS, DS, LNDR

TELECOM STRATEGY

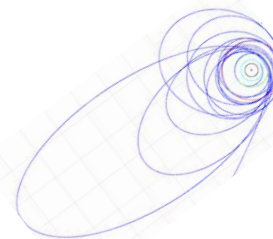
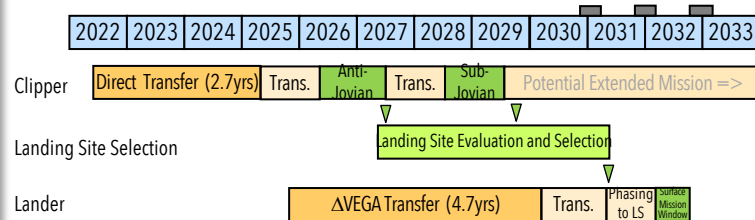
Relay: Cross-band Frontier radio
compatible w/ Carrier and Clipper (cont.)
Redundancy: Lander HGA and LGA

DDL Communication: Lander Radio
through DS antenna to CRS HGA Rx
supports 128kbit/sec

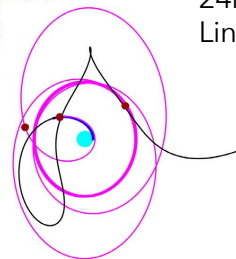
RADIATION

RDF: 2.0 CRS TID $< 3\text{Mrad}$
DOV TID $< 1.5\text{Mrad}$
Lander TID $< 2\text{Mrad}$

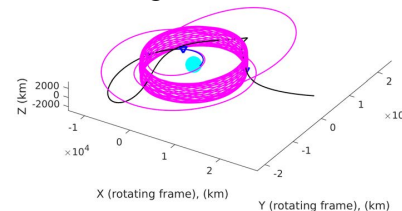
NOTIONAL MISSION PROFILE



Transition to Europa and
Phasing to Landing Site using
Callisto and Ganymede flybys



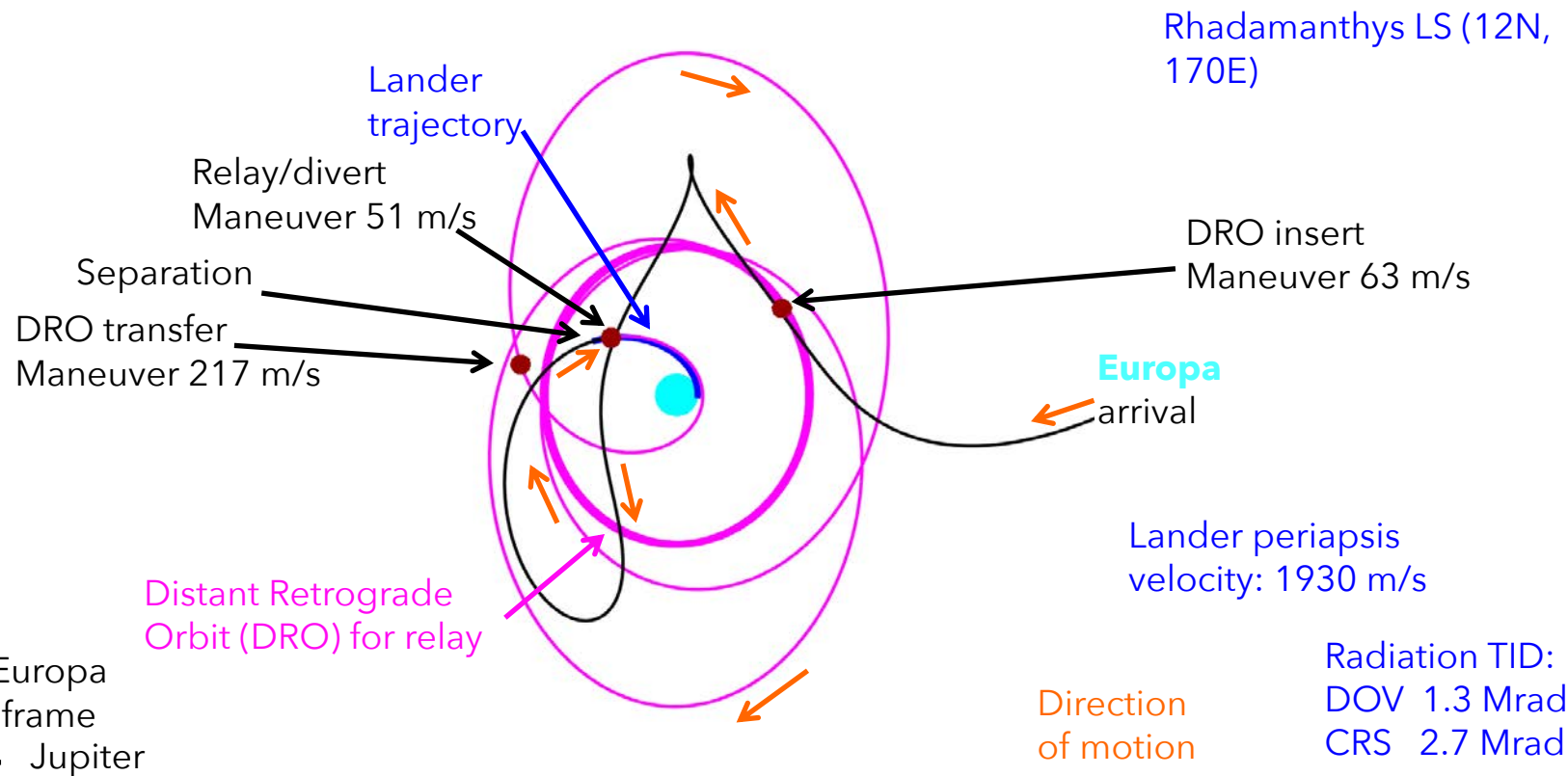
3-body option for lander delivery
and Distant Retrograde Orbit (DRO)
24hr relay orbit to Rhadamanthys
Linea (ref. landing site)



DRO:



Notional Delivery to Relay trajectory: 3-body into DRO

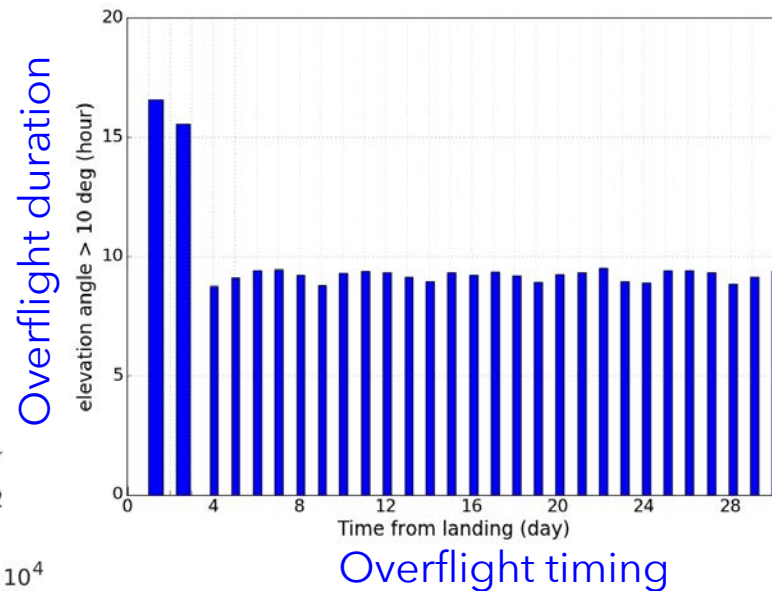
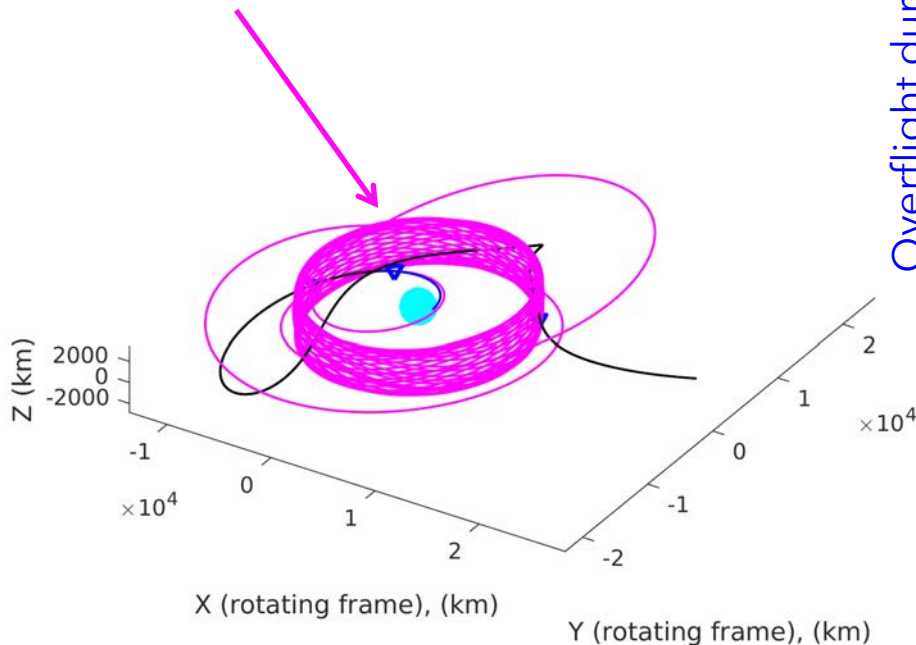




3-body perspective view and CRS-LS elevation-time plot

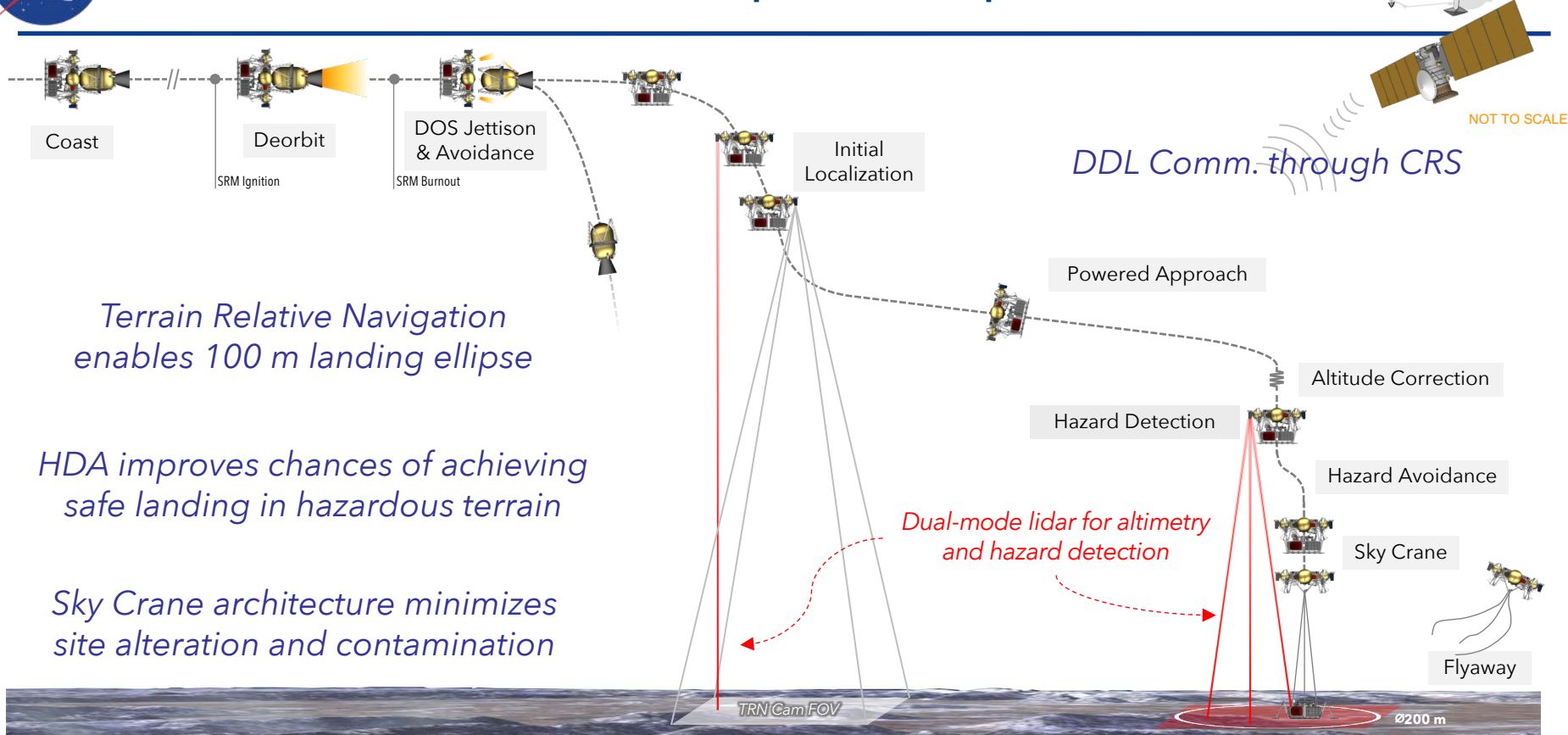
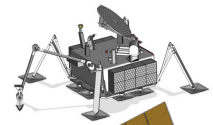


Distant Retrograde Orbit (DRO) for relay





DDL Concept of Operations



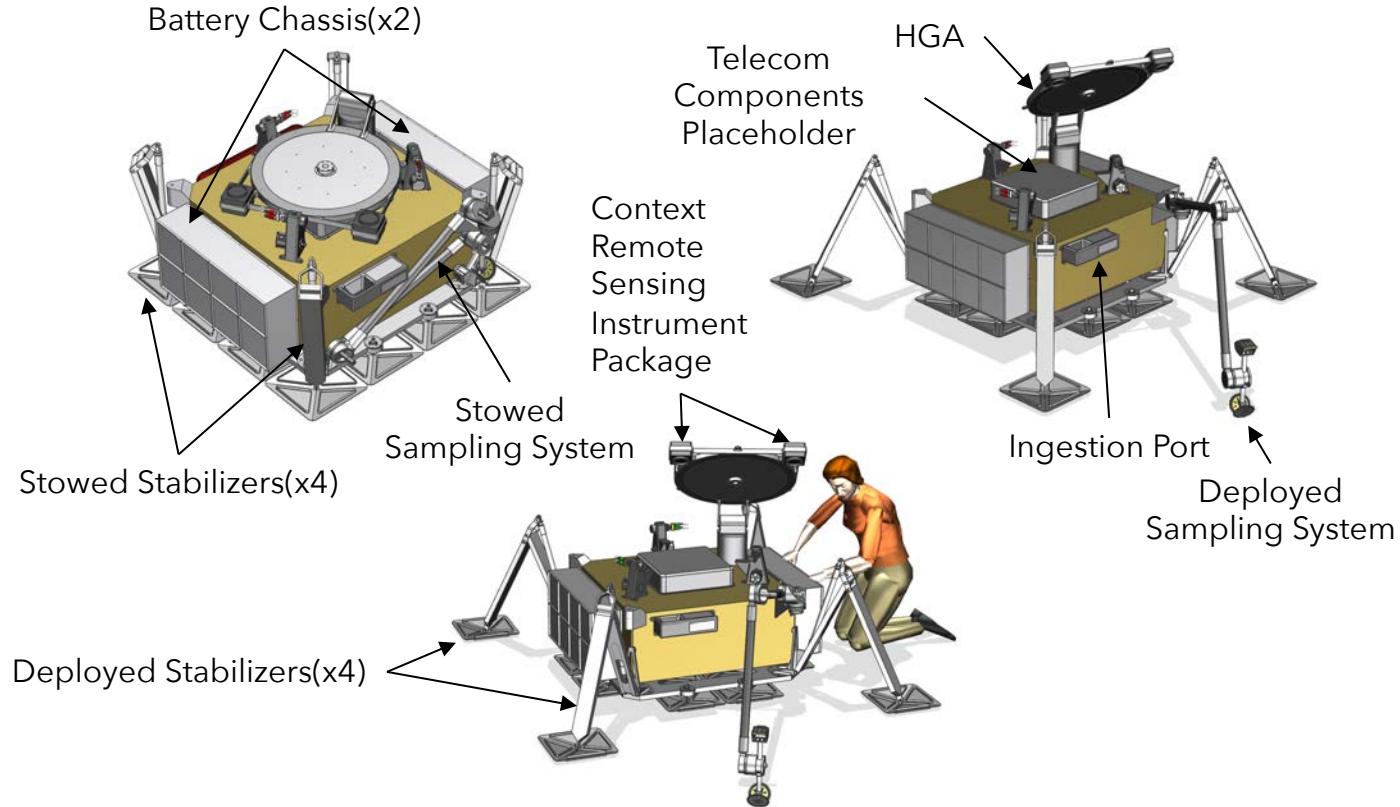
*Terrain Relative Navigation
enables 100 m landing ellipse*

*HDA improves chances of achieving
safe landing in hazardous terrain*

*Sky Crane architecture minimizes
site alteration and contamination*

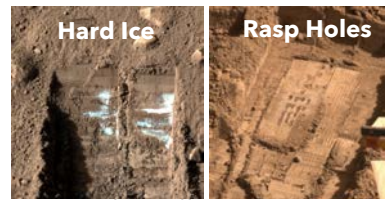


Baseline Lander Configuration





Proposed Sampling System Hardware Is a Mix of Heritage and New Development



Sample Collection Device
(Phoenix Heritage + Packaging)



Sample Excavation



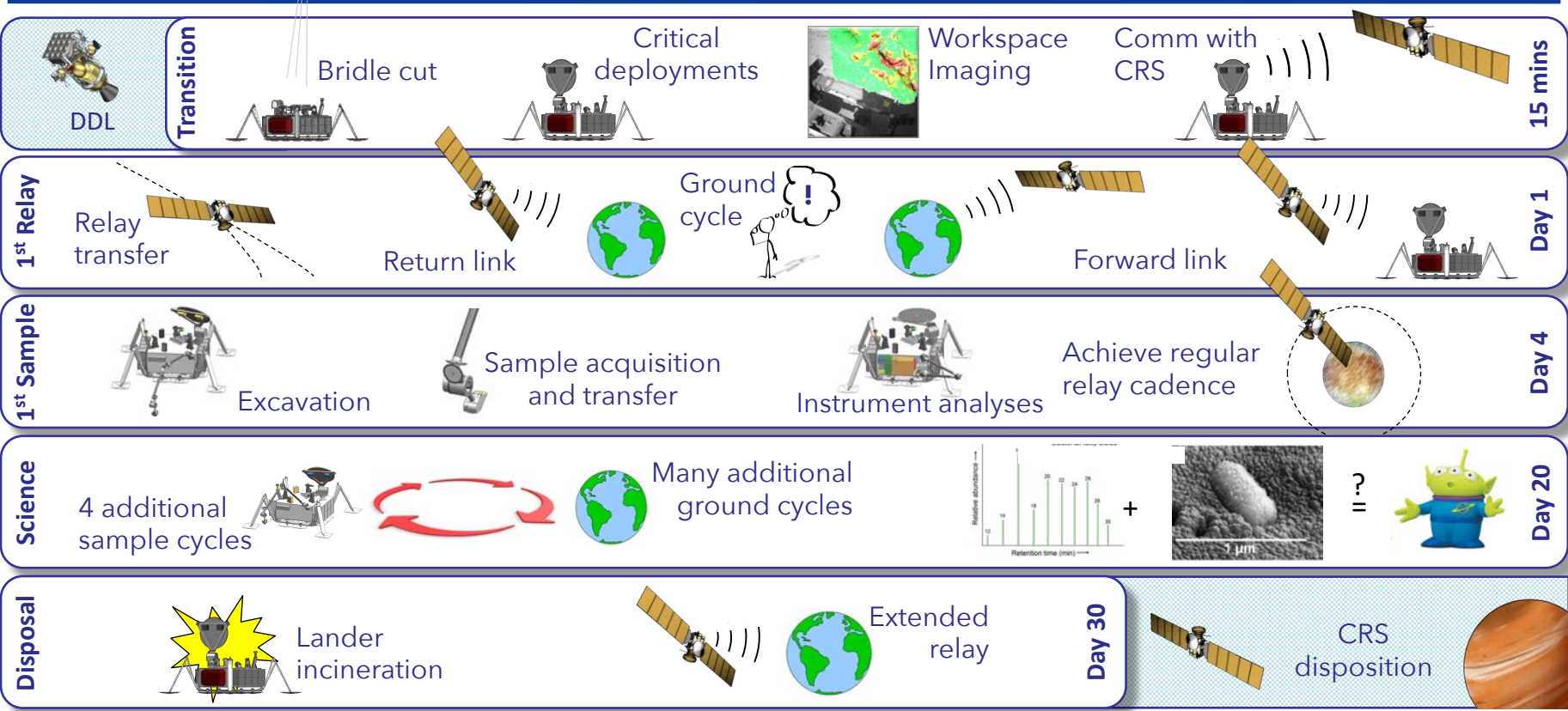
Sample Transfer Dock and Mechanism
(Not Shown: Payload Doors/Covers)

Robotic Arm

Stereo Imagers (Payload)

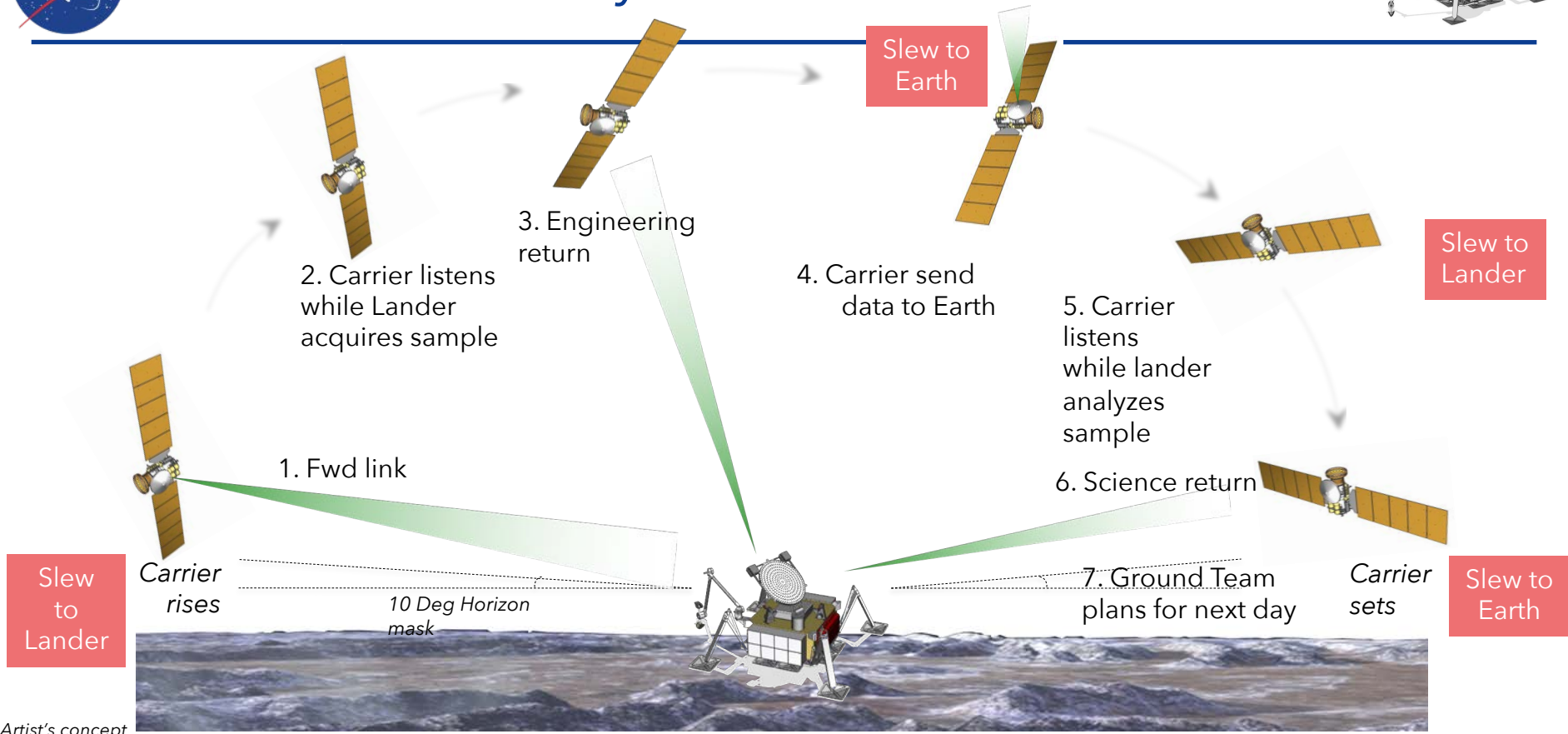
Not shown:
Sampling System CC Barrier



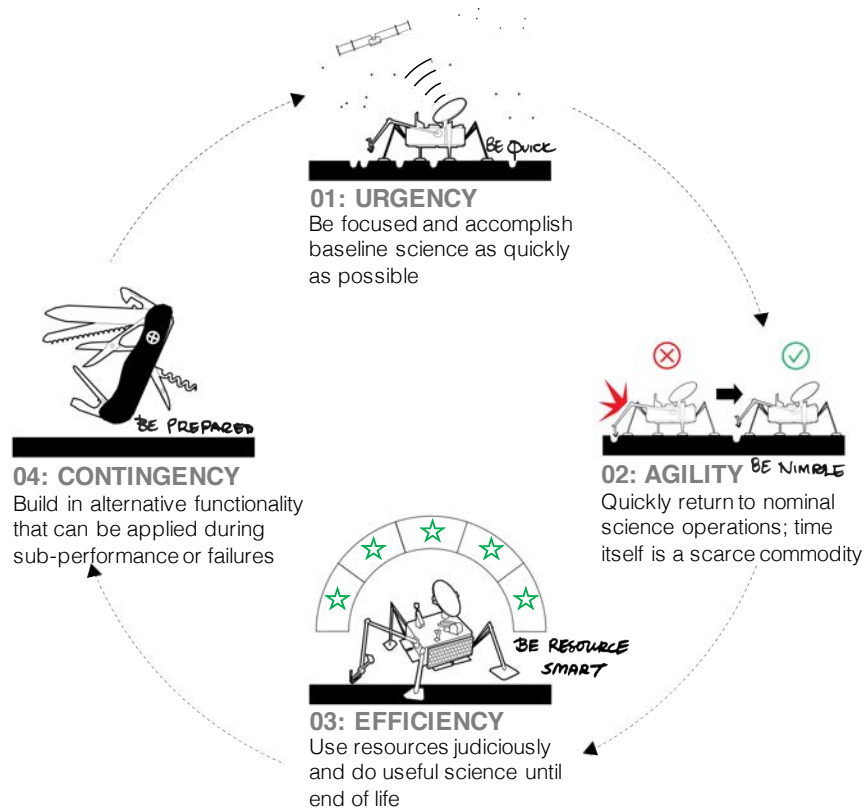
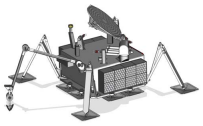




A Day in the Life of Lander



Artist's concept



- **Urgency Principle**

- Be able to accomplish the science objectives as quickly as possible
- Focus on the accomplishment of threshold science as the highest priority

- **Agility Principle**

- Return to science objectives as quickly as possible; time itself is a scarce commodity

- **Efficiency Principle**

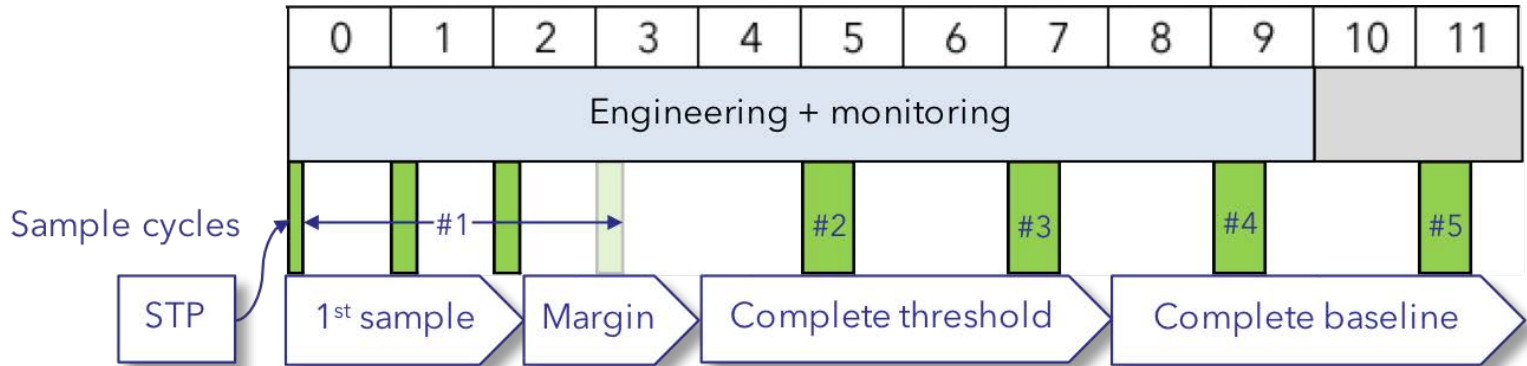
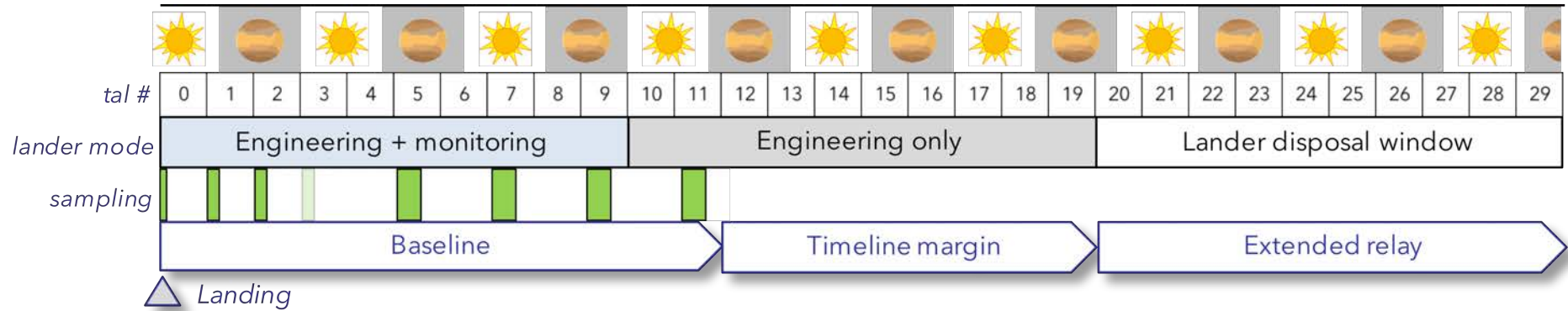
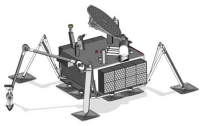
- Use resources judiciously
- Use all unutilized margin for science activities; do useful science until end-of-life

- **Contingency Principle**

- Build in alternative functionality that can be applied in the presence of anticipated sub-performance or failures

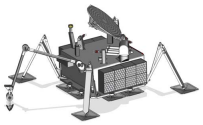


Proposed Surface Timeline





Key Architectural Principles

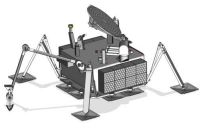


Choices that have influenced the Lander system design

1. Maximize science success in the presence of challenges
2. Clipper system dependency
 - Maximum reuse of subsystems and components
 - Clipper reconnaissance
3. Robust to Environmental Uncertainty
 - Interrupts are considered nominal in high radiation
 - Tolerate maximum topography within resources
 - Day and night surface operations
4. Functional Partitioning
 - Maximize access to Europa Surface
 - Do not use gravity for sample transfers
5. Optimize end-to-end Reliability
 - Independent flight stages with focused objectives
 - Modularized systems where feasible
 - Overlapping requirements where feasible



Conclusions & Next Steps



1. Completed an MCR in June of 2017
2. Since project worked with a HQ-chartered formulation team to explore lower cost options
3. Team is proceeding to develop a modified concept that uses Direct-to-Earth communication as an alternative to relay through the carrier
4. DTE architecture protects the resource allocations for SDT defined model payload
5. Technology and engineering developments are on-going



Europa Lander Concept



KEY CHARACTERISTICS FROM SDT

Number of samples: 5
Sample Depth: 10 cm
Payload Mass: 42.5 kg
Surface Duration: 20 days

PAYLOAD

GCMS	16.4 kg (CBE)
Raman Spectrometer	5.4 kg (CBE)
Context Cameras	4.3 kg (CBE)
Broadband Seismometer	1.2 kg (CBE)
Microscopic imager	5.4 kg (CBE)

DOS & DESCENT STAGE

Descent Engines: 8x MR-104, pulsed

TVC Engines: 4x MR-104 engines, pulsed

ACS Engines: 8x MR-106 engines, pulsed

Small solids (3x Star-3) on DOS to aid separation

FLIGHT SYSTEM

CRS Mass (MPV): 13,710 kg
PDV Mass (MPV, dry): 1183kg
DOV Mass (MPV): 2670kg
Lander Mass (MPV): 480 kg
(438.5 kg FS + 42.5 kg Payload)

LANDER

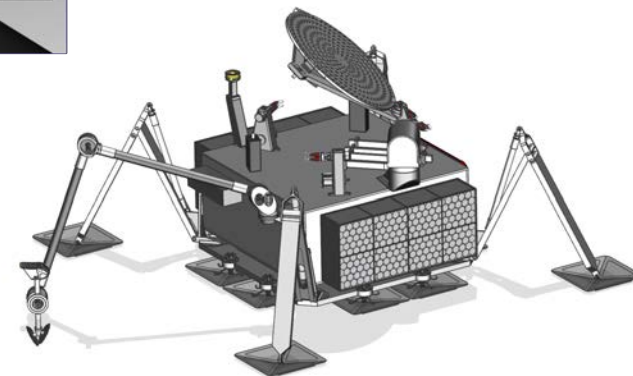
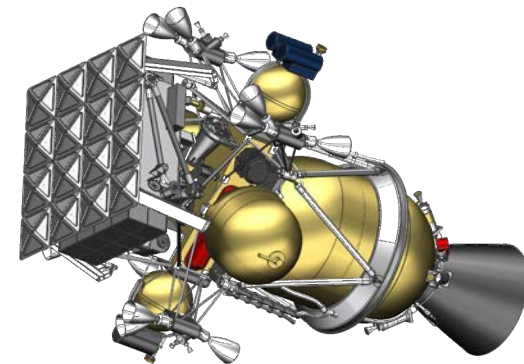
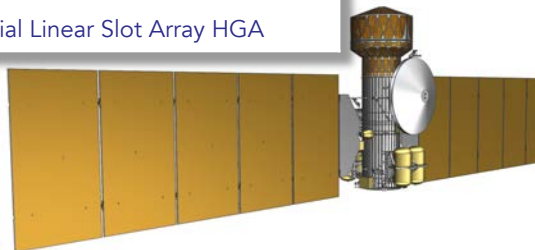
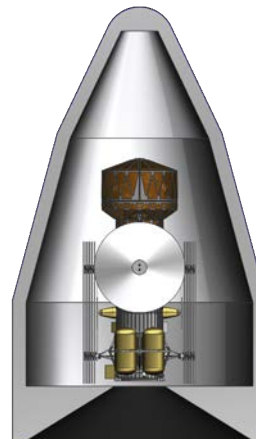
Rectangular vault with adaptive stabilizers

Notional Terminal Sterilization System (30 kg plus volume)

Volume/power efficient motor controller

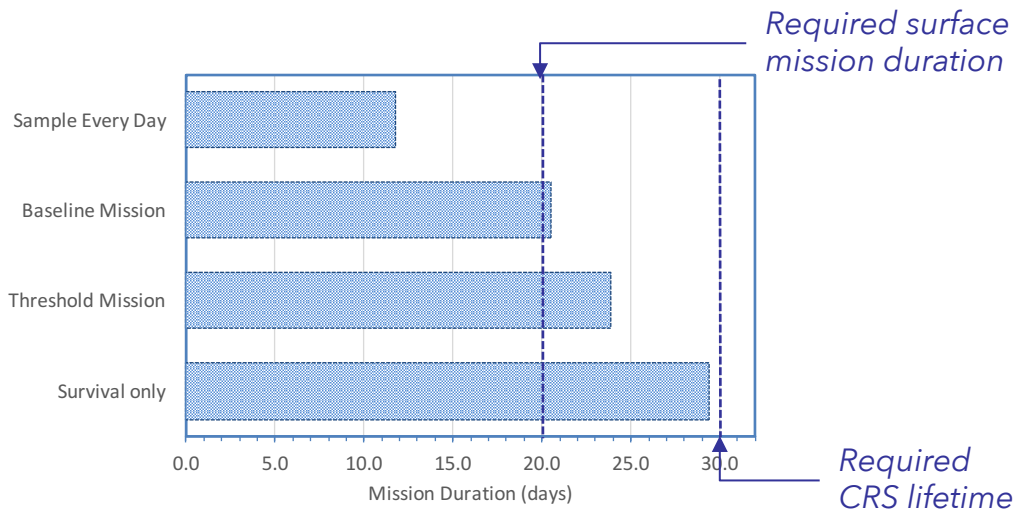
8.5mm vault thickness also used for primary structure

0.6 m Radial Linear Slot Array HGA





Mission Completion

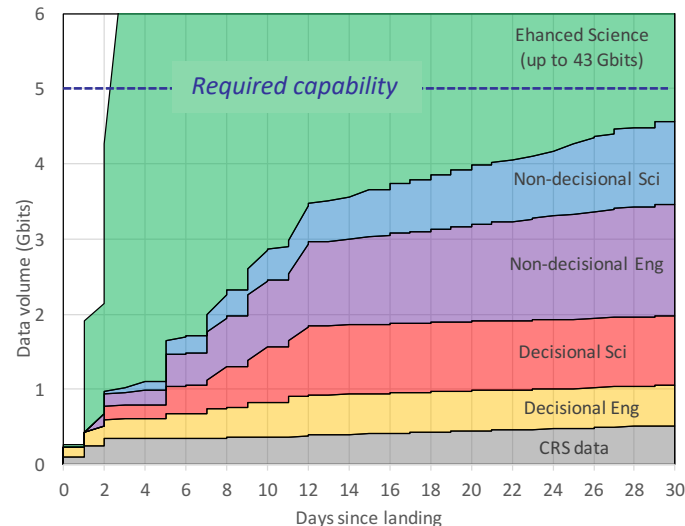


Mission Duration

- Depends on scenario (especially # samples)
- Battery sized for 20 day, 5 sample baseline
- Longer threshold mission supports Clipper flybys

Total Data Return

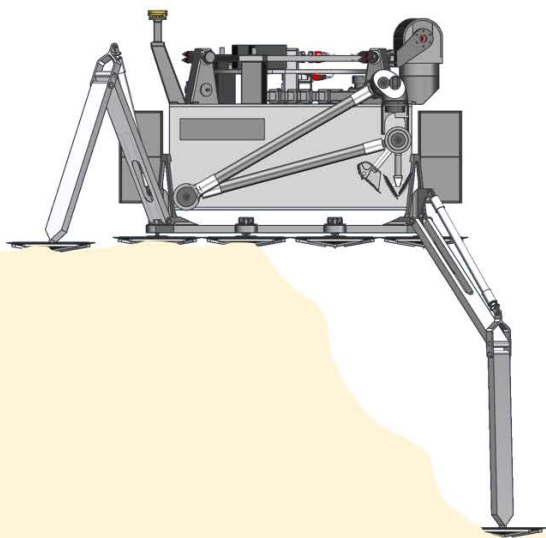
- Required capability is 5 Gbits
- Expected capability is up to 47 Gbits
- Utilize margin for *enhanced* science



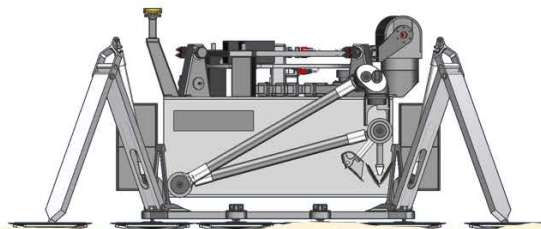
Landing Stabilizers



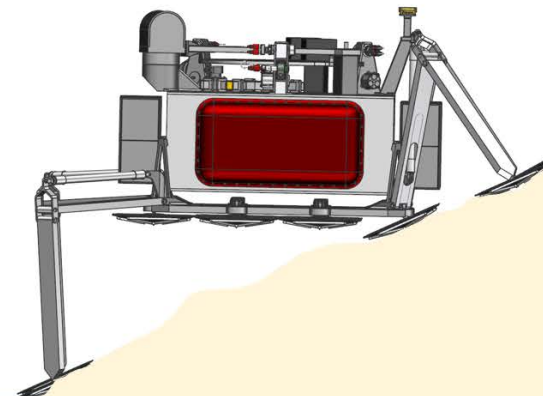
Terrain relief tolerance ≤ 1 m
 V_V @ Touchdown ≤ 0.8 m/s
 V_H @ Touchdown ≤ 0.3 m/s



Survival



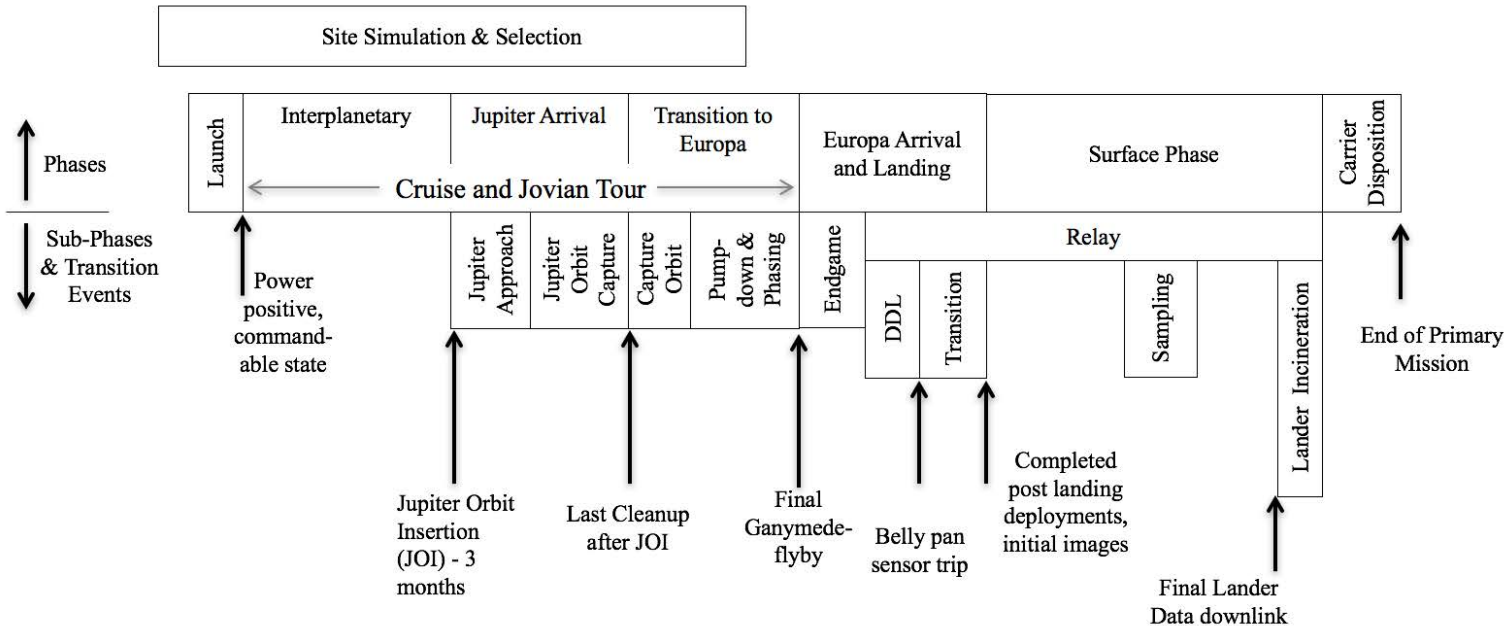
Nominal



Off-Nominal



Europa Lander Concept Mission Phases



Europa Lander has distinct mission phases where flight system and operations are very different.



Mission Trajectory Elements

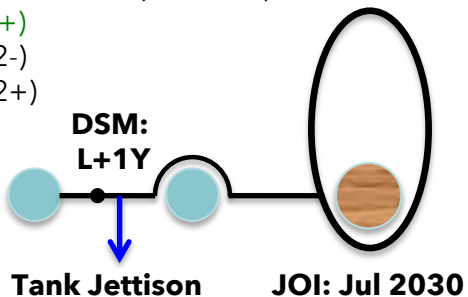


1. Interplanetary Transfer (ΔV -EGA)

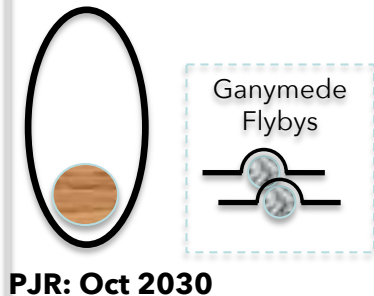
Baseline: 2025 (2+)

Alternate: 2025 (2-)

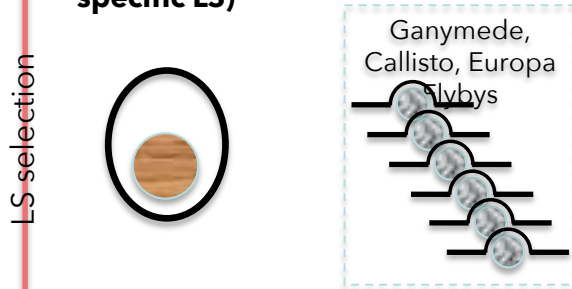
Alternate: 2026 (2+)



2. Early Jupiter Tour (Initial Pump-Down)



3. Later Jupiter Tour (Phasing to specific LS)



4. Europa Low-Energy Capture



4A. Europa Orbit Insertion (for elliptical option)

5. Lander Delivery



6. Transition to Relay



7. Relay Insertion



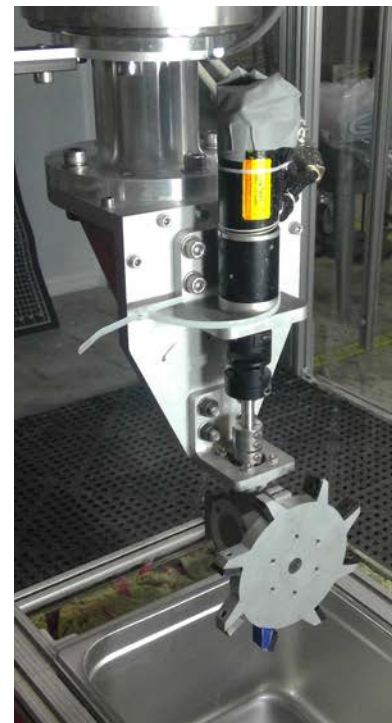
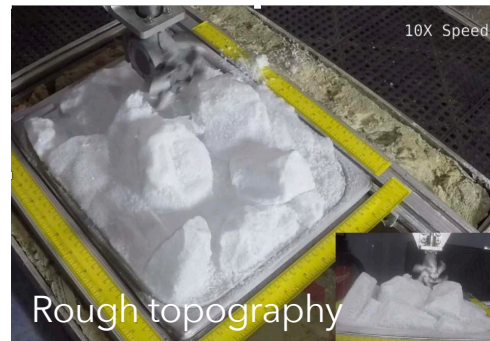
8. Relay



9. Disposal

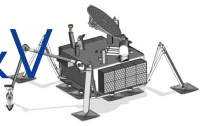


Sampling System Excavation Tools: V-Saw (baseline) and Right-Angle







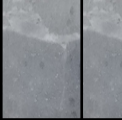
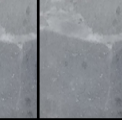
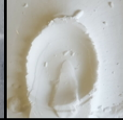







Defining Materials and Topographies for V&V



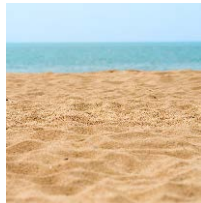
"Hard to cut" is relative - each material has its own challenges associated

											
MMS Dust	Minus 30 Sand	Loose Ice	Comet Simulant	Grill Brick	Lake Koehn Evaporite	250 K	190 K	123 K	Saltwater Ice	Composite Cryogenic Ice	Kramer Massive Mudstone
<ul style="list-style-type: none"> Granular and loose materials Low to high bulk density Moderate to high angle of repose 			<ul style="list-style-type: none"> Porous to "granular" solids Low density Low compressive strength 			<ul style="list-style-type: none"> Crystalline to fractured and refrozen Zero to saturated salinity 			<ul style="list-style-type: none"> Uniform to composite solids High toughness 		

Topographical roughness presents different challenges at different scales



Salt Flats



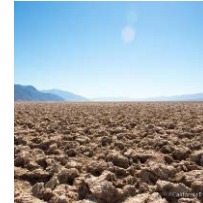
Beach



Gravel Bed



Cobblestone Street



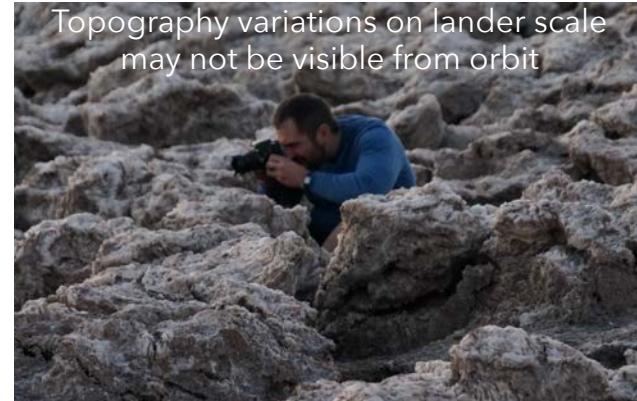
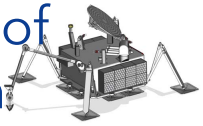
Devil's Golf Course



Chilean Penitentes



Devil's Golf Course in Death Valley represents one type of potentially challenging terrain for the sampling system

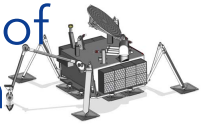


Key point: robustness to unknown topography fundamentally drives our design.

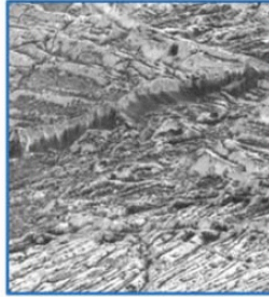




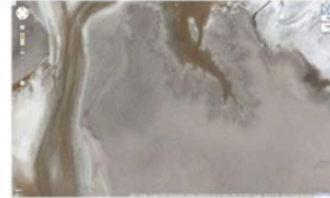
Devil's Golf Course in Death Valley represents one type of potentially challenging terrain for the sampling system



Earth glacier surfaces



Europa at 12 m/pixel
and 10 m/pixel



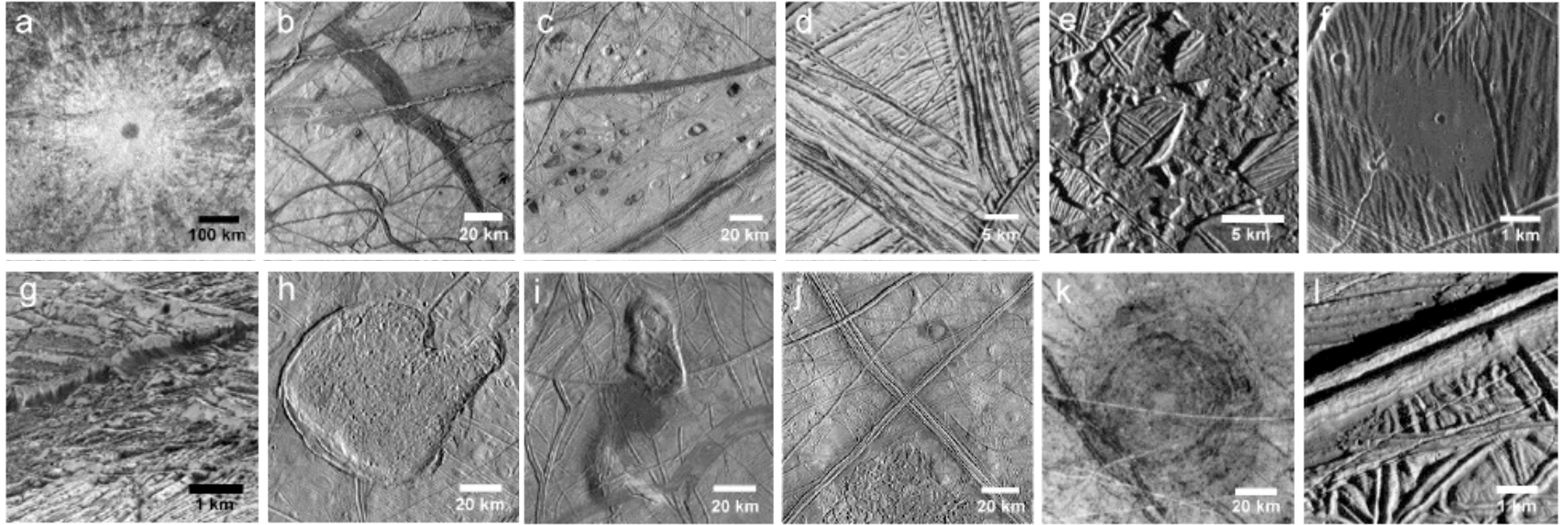
1 m/pixel

Devil's Golf Course –
Death Valley





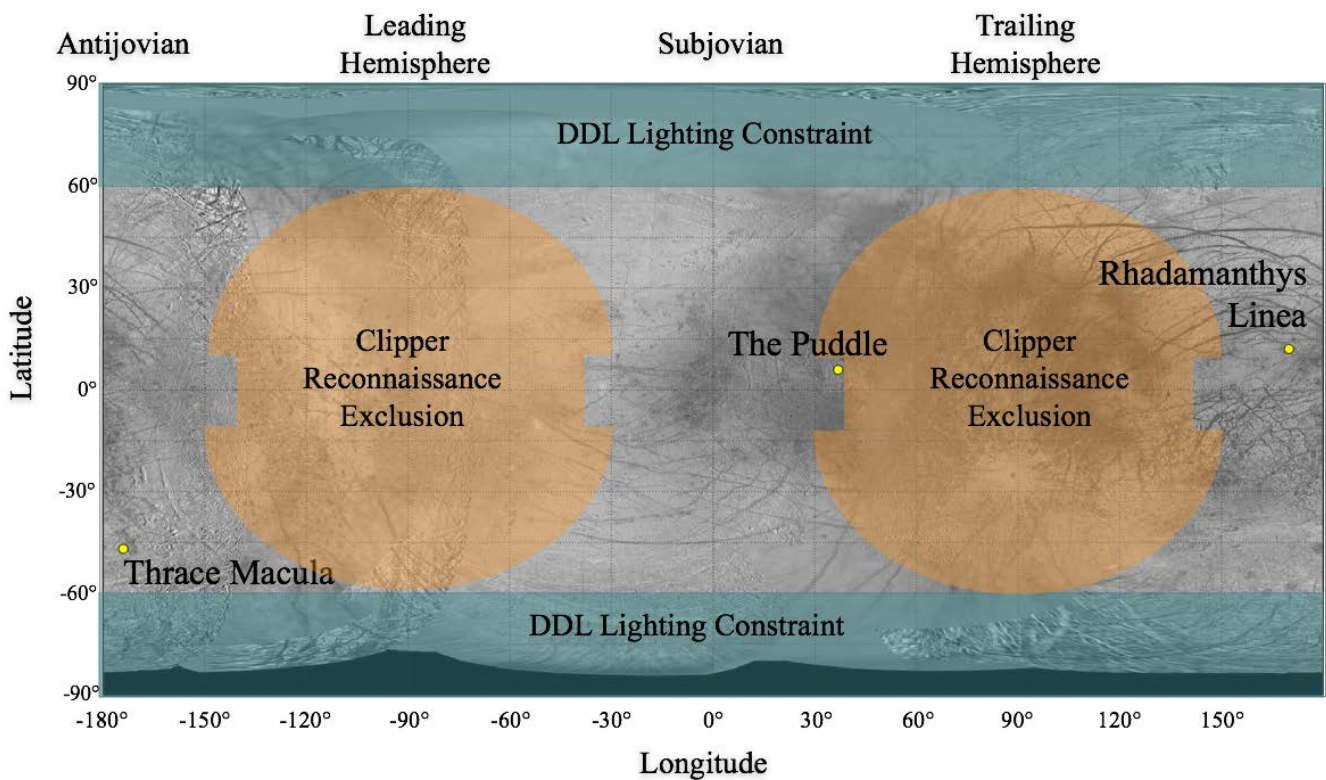
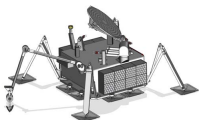
Galileo Images Show Europa Having Rugged, Unusual Terrain



Clipper datasets would substantially improve upon the highest resolution imaging (~6-12 m/pixel) previously acquired by Galileo.



Reference Landing Sites





Galileo, 1610

